JOURNAL OF•BALTIC SCIENCE EDUCATION

ISSN 1648-3898 /Print/
ISSN 2538-7138 /Online/

EFFECTS OF BIOMIMICRY-ENRICHED ENGINEERING DESIGN-BASED TEACHING ON STUDENTS' ASSOCIATION WITH DAILY LIFE, STEM ATTITUDE, AND BIOMIMICRY ATTITUDE IN SOUND AND ITS PROPERTIES UNIT

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Abstract. *This study examined the effects of biomimicry-enriched engineering design-based teaching on sixth graders' daily life associations, STEM attitudes, and biomimicry attitudes in the "Sound and Its Properties" unit. A pre-test post-test quasi-experimental design was used, with four classes randomly assigned to experimental and control groups. The study involved 109 sixth graders in Türkiye. The experimental groups received biomimicry-enriched engineering design-based teaching for 22 hours, while the control groups followed the existing curriculum. The Association with Daily Life Test (ADLT) in the sound topic, Biomimicry Attitude Scale (BAS), and STEM Attitude Scale (SAS) were administered as pre-tests and post-tests to collect data. The post-test scores of the students' association with daily life, biomimicry attitude, and STEM attitude were compared using Multivariate Analysis of Covariance (MANCOVA) when their pre-test scores were controlled. The findings of the study revealed that the students in the experimental group had significantly higher levels of association with daily life, STEM attitude, and biomimicry attitude compared to those in the control group, with the most substantial impact on association with daily life in the sound topic.*

Keywords: *biomimicry-enriched teaching, engineering design-based teaching, biomimicry attitude, STEM attitude, association with daily life.*

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Introduction

Among the primary problems in science education, a plethora of issues are listed such as: an overly content-heavy curriculum, the inability to connect scientific knowledge with daily life, insufficient connection between disciplines and topics, the inability of students to transfer concepts to different situations or environments, insufficient emphasis, and inadequacies in answering students' questions of "why do I need to learn this?" Previous studies (Demircioğlu et al., 2009; Gilbert, 2006; Gürel, 2017; Pilot & Bulte, 2006) asserted that various methods and approaches are needed to address these problems encountered during the teaching-learning process, to cultivate scientific literacy in students, and to enable them to acquire higher-order thinking skills. It is emphasized that connecting science lessons to daily life is essential for this purpose (Gilbert, 2006). Pilot and Bulte (2006) and Kaltakci-Gurel (2018) argued that when science education is relevant to students' lives and interests, their comprehension of the subject improves. Education systems worldwide are increasingly focusing on equipping students with problem-solving skills and interdisciplinary approaches to science and technology. STEM (Science, Technology, Engineering, and Mathematics) education aims to integrate these disciplines to enhance students' cognitive abilities and prepare them for real-world challenges (Aksoy et al., 2023; Aydin-Gunbatar et al., 2018; Rehmat et al., 2024). Within this educational paradigm, innovative teaching strategies such as engineering design-based learning have been introduced to engage students actively in science education (Fortus et al., 2005; Mohd Shahali et al., 2016; Wendell & Lee, 2010). Recent studies suggest that incorporating biomimicry—a practice that draws inspiration from nature to solve human challenges—can enhance students' learning experiences in

https://doi.org/10.33225/jbse/25.24.918

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

STEM fields by fostering creativity and innovation (Avcı, 2019; Gardner, 2012; Pauls, 2017). Biomimicry allows students to apply scientific knowledge in practical contexts, encouraging the association of scientific concepts with everyday life. The current study aims to examine the effectiveness of biomimicry-enriched engineering design-based teaching as an innovative approach relevant to real-life situations and students' attitudes. The "sound and its properties" unit was selected as the science topic because, while previous studies have found sound to be a challenging concept for learners, there is limited research on effective methods for teaching students about sound and its relevance to their daily lives (Aksoy et al., 2023; Eshach & Schwartz, 2006; Faletič, 2023).

Biomimicry in Science Education

In her 1997 book, Biomimicry: Innovation Inspired by Nature, Janine Benyus (1997) introduced a new approach to learning from nature. The term biomimicry was derived from the Greek words bios (life) and mimesis (imitation). It is an interdisciplinary approach that seeks inspiration from nature's patterns and strategies to solve human challenges. This approach goes beyond mere imitation; it involves understanding the core principles of natural processes and adapting them to human engineering, design, and innovation. Biomimicry has been instrumental in revolutionizing various sectors, including medicine, architecture, materials science, and engineering (Sedira et al., 2024; Yeter et al., 2023). Biomimetic innovations in these scientific and technological disciplines have led to advancements such as self-cleaning surfaces inspired by lotus leaves, energy-efficient building designs that mimic termite mounds, and high-performance adhesives modeled after gecko feet. Beyond its practical applications, biomimicry is increasingly being incorporated into education, as it provides a unique way to engage students by linking biology and engineering with real-world applications. The integration of biomimicry into educational curricula helps bridge the gap between theoretical knowledge and real-world applications, making biomimicry a highly effective and engaging approach for students. Several studies in the literature emphasize the importance of teaching and teaching with biomimicry to foster critical thinking, creativity, innovation, association with daily life, and problem-solving skills (Ersanlı, 2016; Gardner, 2012; Jacobs et al., 2022; Kandemir et al., 2022; Qureshi, 2022; Rehmat et al., 2024; Savran Gencer et al., 2020; Sumrall et al., 2018). These studies mainly focused on students' biomimicry perceptions and awareness (Sağır et al., 2022; Sürgü & Güneş, 2022; Velioğlu & Yakişan, 2022; Yakişan & Velioğlu, 2019), how students conceptualize and engage in biomimicry (Qureshi, 2022; Yeter et al., 2023), development of biomimicry activity and teaching approach (Canbazoğlu Bilici et al., 2021; Coban & Coştu, 2023; Savran Gencer et al., 2020; Sumrall et al., 2018), associating biomimicry examples with daily life (Ersanlı, 2016; Kandemir et al., 2022). However, the number of studies in teaching science concepts with biomimicry is still relatively small. Some of the approaches involving biomimicry, such as inquiry-based learning (Qureshi, 2022), project-based learning (Jatsch et al., 2023), and engineering design-based teaching (Canbazoğlu Bilici et al., 2021; Coban & Coştu, 2023; Pauls, 2017; Rehmat et al., 2024) are proposed to help students not only understand scientific concepts but also apply these concepts to solve complex, real-world challenges. By integrating biomimicry into these educational strategies, educators can inspire the next generation of thinkers and innovators, particularly in STEM fields, while promoting sustainability and environmental stewardship.

Engineering Design-Based Teaching

Recent studies have highlighted the importance of STEM education in fostering global competitiveness. The need to equip individuals with strong STEM skills to meet the demands of the modern workforce is emphasized by several studies (Aydin-Gunbatar et al., 2018; Bissaker, 2014; National Center for Science and Engineering Statistics [NCSES], 2023; National Research Council [NRC], 2012; Ring et al., 2017). However, employers often struggle to find employees with the ability to apply scientific and technological knowledge to develop innovative solutions to real life problems. STEM education has emerged as a promising approach to address this challenge. By combining science, technology, engineering, and mathematics, integrated STEM instruction focuses on solving real-world problems through practical applications (Aydin-Gunbatar et al., 2018; Korur et al., 2017). The integration of these fields should be grounded in engineering design and problem-solving, as emphasized by the National Research Council [NRC] (2012) and Next Generation Science Standards [NGSS] (2013). Engineering design is a key component of effective STEM education. In this respect, previous studies (Apedoe et al., 2008; Aydin-Gunbatar et al., 2018; Burrows et al., 2014; Delen & Yuksel, 2022; Kolodner, 2002) emphasized the importance of incorporating engineering design into science teaching. Through engineering design processes, students engage in activities such as analyzing situations, collecting information, brainstorming solutions, developing models, and testing

https://doi.org/10.33225/jbse/25.24.918

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

prototypes (NRC, 2012; NGSS, 2013). Studies have also shown that design-based learning can enhance student performance and attitude by engaging students in active learning and problem-solving, making it a key factor in the success of integrated STEM education as well as fostering engineering and other higher order skills (Apedoe & Schunn, 2013; Capobianco et al., 2015; Doppelt, 2009; Korur et al., 2017; Mehalik et al., 2008; Silk et al., 2009). The success of integrated STEM education depends on innovative applications and practices. Ring et al. (2017) and NRC (2014) highlight the need for new approaches to effectively implement integrated STEM education and engineering design processes. By adopting these strategies, educational systems can better prepare students for the challenges of the 21st century. Hynes et al. (2011), Marulcu and Sungur (2012), and National Aeronautics and Space Administration [NASA] (2023) proposed several frameworks for integrating science and engineering through engineering design-based teaching. This study innovated upon the existing engineering design process cycles by integrating biomimetic applications. As depicted in Figure 1, this novel process was employed in experimental group activities in the current study.

Integration of Biomimicry and Engineering Design-Based Teaching

Combining biomimicry with engineering design-based teaching creates a powerful educational approach that encourages innovation and sustainability in problem-solving. By using biomimicry as a central theme in engineering design-based teaching, students learn to approach problems systematically, considering both functionality and environmental impact. In the integration of biomimicry and engineering designs, biomimicry can be approached from two primary perspectives: bottom-up and top-down (Aziz & El Sherif, 2016), which can also be used for educational purposes. The first bottom-up perspective involves applying biology to design, where a biological phenomenon provides a new solution to a design problem. The second top-down approach is design-to-biology, where a design problem is identified, the core function is defined, and then observations are made of how organisms and ecosystems fulfill this function.

Engineering design-based activities that incorporate the biomimicry approach affect students' understanding of biomimicry, creative thinking and help them develop different perspectives on nature and gain a positive attitude towards the idea of biomimicry (Canbazoğlu Bilici et al., 2021; Coban & Coştu, 2023; Gardner, 2012; Pauls, 2017). Engaging in engineering design activities based on these principles can further deepen their comprehension of biomimicry and its applications. Gardner (2012) highlighted the significance of design-based biomimicry activities that incorporate science content, particularly at the molecular and nanoscale levels, in promoting a deeper understanding of biomimicry. Gardner's study (2012) demonstrated that a biomimetic matching cards activity can effectively enhance students' understanding of biomimicry principles. In this activity, students were required to match cards depicting organisms with cards showcasing related technologies, fostering discussions about the innovation process used by researchers. In the study by Canbazoğlu Bilici et al. (2021), lower-secondary school students were tasked with designing eco-friendly vehicles inspired by nature that could help reduce air pollution. Through this activity, students learned about engineering design, biomimicry, air pollution, and the structural features of different organisms. The study suggests that incorporating biomimicry-based design activities into STEM classrooms can be a valuable learning experience for students. Similarly, Coban and Coştu (2023) sought to integrate biomimicry into science education for fifth-grade primary school students. The researchers developed a teaching approach incorporating a biomimicry design model and implemented it in a Turkish fifth-grade classroom. The approach involved introducing students to various organisms, explaining the concept of biomimicry, and guiding them through a nature-inspired design process. After completing the lessons, students created their own designs based on the studied organisms. The results indicated that the activities enhanced the participants' creativity. However, the study found that students primarily relied on information provided during the design process. This underscores the importance of a strong foundation of knowledge and practical experience to fully realize the potential of nature-inspired design. A rich learning environment that fosters students' curiosity and interest is proposed as essential for cultivating their creativity and innovation. In similar applications combining STEM and biomimicry, studies have concluded that students can develop innovative solutions to real-world problems by utilizing their imagination and applying the biomimicry approach in conjunction with engineering design principles (Alperen, 2020; Pauls, 2017; Savran Gencer et al., 2020; Yakişan & Velioğlu, 2019).

To sum up, biomimicry offers a unique way of bridging the gap between biology, engineering, and education. In general, it serves as a sustainable and innovative approach to solving real-world problems. In science education, it provides students with a creative and engaging platform to explore biological principles and their applications in technology and engineering. Finally, integrating biomimicry with engineering design-based teaching fosters

https://doi.org/10.33225/jbse/25.24.918

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

a comprehensive learning experience that prepares students for the challenges of modern engineering while promoting sustainability and innovation.

Research Aim and Research Question

Innovative teaching methods are needed to help students develop problem-solving skills and find practical solutions to real-world challenges in everyday contexts. In this context, it was thought that teaching science with engineering design-based approaches would help students find practical solutions to their problems, develop their creative designs, and improve their ability to apply the design process. As stated in previous studies (Canbazoğlu Bilici et al., 2021; Gardner, 2012; Pauls, 2017; Savran Gencer et al., 2020), biomimicry activities offer an important opportunity to teach STEM (Science, Technology, Engineering, and Mathematics) fields with an integrated approach. By examining nature and producing creative solutions to encountered problems, developing these designs, and integrating them into engineering design practices, students can identify and be inspired by the solutions produced by other living things in nature while overcoming their own challenges. This approach has the potential to be groundbreaking and beneficial for students' learning as well as attitudes, and the present study is one of the pioneering experimental studies integrating biomimicry into engineering design in science education. While there has been growing interest in biomimicry in education, there is still limited research on its impact on students' attitudes towards STEM and their ability to relate scientific concepts to daily life. Existing studies have focused primarily on its use in high school and higher education, leaving a gap in understanding its effectiveness in primary and lower-secondary school settings. This study aimed to fill that gap by examining how sixth graders' attitudes towards STEM and biomimicry and their association of science with everyday experiences are influenced by biomimicry-enriched engineering design-based teaching. While this study is situated within a specific educational context, the challenges it addresses—fostering students' connection to daily life, enhancing STEM attitudes, and promoting innovative thinking through design—are universal concerns across diverse educational systems worldwide. Therefore, the insights gained from examining biomimicry-enriched engineering design-based teaching hold significant potential for global applicability and can inform pedagogical practices in various international settings.

Building on this framework, the present study examined the effects of biomimicry-enriched engineering design-based teaching on sixth-grade students' STEM attitudes, association with daily life in the context of the sound concept, and their biomimicry attitudes. Specifically, the study aimed to answer the following research question:

Is there a significant mean difference between the post-test scores of the experimental and control groups exposed to biomimicry-enriched engineering design teaching and conventional teaching on "sound and its properties unit" regarding attitudes towards biomimicry, association with daily life, and attitudes towards STEM, when the pre-test scores are controlled?

Research Methodology

General Background

In this study, a quasi-experimental design with a pretest-posttest control group was used. The experimental group received lessons with biomimicry-enriched engineering design-based applications, while the control group followed the existing curriculum for the sixth-grade "sound and its properties" unit. Pre- and post-tests were administered to both groups to assess changes in their associations with daily life, attitudes towards biomimicry, and attitudes towards STEM.

To ensure the equivalence of the groups before the intervention, a biomimicry awareness questionnaire (BAQ) was administered to all students. Based on the results, classes were randomly assigned to experimental and control groups. All groups took pre-tests one week before the implementation, the treatment was given in four weeks (22 lesson hours), and the study concluded with administering post-tests. Table 1 outlines the implementation steps of the quasi-experimental design in this study.

https://doi.org/10.33225/jbse/25.24.918

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

Table 1
Symbolic Representation of Quasi-Experimental Design in Study [1]

Group	Matching	Pre- Test	Intervention	Post- Test
Experimental	BAQ	• pre-ADLT • pre-SAS • pre-BAS	Engineering design-based lesson plans enriched with biomimicry approach	• post-ADLT • post-SAS • post-BAS
Control	BAQ	• pre-ADLT • pre-SAS • pre-BAS	Existing/standard curriculum lesson plans	• post-ADLT • post-SAS • post-BAS

[1] BAQ: Biomimicry Awareness Questionnaire, ADLT: Association with Daily Life Test, SAS: STEM Attitude Scale, BAS: Biomimicry Attitude Scale

Participants

By a combination of purposive and convenience sampling methods, four intact classes were selected for this study. Two criteria were considered in selecting classes: first, the availability of the classes to the researcher, and second, teachers with at least two classes were selected to eliminate the instructor and researcher effects on internal validity. The sample for this study consisted of 109 sixth-grade students from a state elementary school in Ankara, Türkiye. Of these students, 59 were female (54.13%) and 50 were male (45.87%). Four classes were randomly assigned to experimental and control groups: two experimental groups and two control groups. Before the group assignment, a biomimicry awareness questionnaire (BAQ) was administered to all students. As there were no significant differences in BAQ scores among the classes, random assignment was used. The experimental group included 57 students (52.3%), and the control group included 52 students (47.7%). Two of the four classes were taught by the researcher, while the other two were taught by a different science teacher at the same school. One experimental and one control group were assigned to each teacher. Table 2 provides the student distribution in each group and teacher.

Table 2
Distribution of Sixth Grade Students in the Sample

Groups	Teachers	Female		Male		Total	
		N	(%)	*N*	(%)	*N*	(%)
Experimental-1	Teacher-1	17	15.6	13	11.9	30	27.5
Control-1		12	11	14	12.8	26	23.8
Experimental-2	Teacher-2	16	14.7	11	10.2	27	24.9
Control-2		14	12.8	12	11	26	23.8
Total		59	54.13	50	45.87	109	100

Variables

The dependent variables in this study were the post-test scores of students in the experimental and control groups, measured after the implementation of the lesson plans. These post-test scores were labeled as post-BAS, post-SAS, and post-ADLT. The independent variable was the teaching method applied to each group. This variable was designated as "group" in the statistical analyses. The experimental group received engineering design-based lessons enriched with biomimicry applications, while the control group followed the standard curriculum.

To account for potential differences in baseline knowledge, the pre-test scores of pre-BAS, pre-SAS, and pre-ADLT were used as covariates. By controlling for these pre-test scores, the analysis could isolate the impact of the teaching methods on the dependent variables. This allowed for a more accurate assessment of whether the independent variable (teaching method) had a significant effect on the post-test scores.

https://doi.org/10.33225/jbse/25.24.918

ISSN 1648-3898 /Print/
ISSN 2538-7138 /Online/

Instruments

In this study, the biomimicry awareness questionnaire (BAQ), the association with daily life test (ADLT), the biomimicry attitude scale (BAS), and the STEM attitude scale (SAS) were used as data collection instruments. Prior to data collection, all four data collection tools were reviewed by two experts in the field of science education. These expert reviews were used for the content validation. Construct validity was assessed using the item-total score correlation, calculated with Pearson's correlation coefficient (r). Items in the instruments were found to have moderate to high positive correlations with the total scores. The internal consistency of data collection instruments was reported as high, with Cronbach's α reliability coefficients ranging from .610 to .902. In this section, these data collection instruments are explained in detail.

The Biomimicry Awareness Questionnaire (BAQ)

The BAQ was developed by researchers to assess sixth grade students' prior knowledge of biomimicry. After expert review and revisions, the final version of BAQ consisted of 20 items. In the questionnaire, students are asked to identify, from four given options, the living organism that inspired the given biomimetic product design. Students were awarded one point for each correct answer and zero for incorrect answers in the questionnaire. The Cronbach alpha reliability coefficient for the BAQ was calculated as .610. The BAQ, which was applied as a pre-test, was used to determine whether there was a significant difference between the awareness of the students in four classes about biomimicry before the implementation. The BAQ pre-test data we obtained were analyzed using One-Way ANOVA in the IBM SPSS 23 program to see whether there was a significant difference among the classes. The analysis revealed no statistically significant differences in the BAQ pre-test scores among the four participating classes ($F(3, 105) = 0.477$, $p = .699$). Thus, the classes were randomly assigned to the experimental and control groups.

The Association with Daily Life Test (ADLT)

After analyzing the daily life association tests prepared in different subjects (Şahin & Bodur, 2016; Yolagiden, 2021), the ADLT was developed by the researchers to measure sixth-grade students' associations with daily life related to the 'sound and its properties' unit. The test consisted of 25 questions aligned with the curriculum objectives in the subject areas of "sound propagation" (4 items), "hearing of sound in different mediums (6 items), "speed of sound" (4 items), and "interaction of sound with matter" (11 items). Expert reviews and revisions were conducted to ensure the quality of the items. The items in the ADLT were designed as 'true', false', and 'don't know'. Correct answers were coded as 1, incorrect answers were coded as 0, and "don't know" was left blank. The Cronbach alpha reliability coefficient for the ADLT was calculated as .776.

The Biomimicry Attitude Scale (BAS)

In order to measure students' attitudes towards biomimicry in the study, the biomimicry attitude scale (BAS) was developed by the researchers. After the literature review, an item pool consisting of statements that measure biomimicry attitudes was developed. The BAS was de-signed in a 5-point Likert type as 'strongly agree', 'agree', 'undecided', 'disagree', 'strongly disagree'. The 24-item scale was developed by taking the expert opinions of a professor in science education and an experienced science teacher. The Cronbach alpha reliability coefficient was calculated as .845 for the BAS.

The STEM Attitude Scale (SAS)

The SAS, used to measure students' attitudes towards STEM, originally developed by Faber et al. (2013) and translated into Turkish by Yıldırım and Selvi (2015), was used in this study. It has four sub-scales: Science, Mathematics, Engineering and Technology, and 21st Century Skills. The scale consists of 37 items in a 5-point Likert-type scale, arranged as 'strongly agree', 'agree', 'undecided', 'disagree', and 'strongly disagree'. The internal reliability of the whole scale, as calculated by Cronbach's alpha, was found to be .902.

https://doi.org/10.33225/jbse/25.24.918

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

Instructional Materials and Procedure

Lesson Plans for Experimental and Control Groups

Lesson plans are crucial for guiding teachers and ensuring consistent implementation across experimental and control groups to ensure treatment fidelity. In the development of lesson plans, Roobeek's (2019) process was followed. In this study, while preparing the lesson plans, the objectives of the 'sound and its properties' unit were taken into consideration. A literature review was conducted to examine lesson plans previously prepared based on the biomimicry approach and engineering design. As a result of the literature review, biomimicry-enriched engineering design-based lesson plans were created for the experimental group. While preparing the lesson plans of the experimental group, special attention was paid to the contexts and activities that include biomimicry applications, and engineering design-based projects were also integrated into the lesson plans. The lessons for both groups were blended with hands-on activities and experiments in the textbooks within the curriculum. As a result, four biomimicry-enriched engineering design-based lesson plans and four standard curriculum-based lesson plans were prepared for the experimental and control groups, respectively. Table 3 details the implementation activities, objectives, and allocated hours for the lesson plans in both groups.

Table 3
Sixth Grade Sound and Properties Unit Objectives, Lesson Hours and Experimental/Control Group Implementations

Science Topic	Objectives	Lesson Hours	Experimental Group Implementations	Control Group Implementations
Sound Propagation	• Predicts the environments in which sound can propagate and tests their predictions.	4	• Oilbirds and Effects of Noise Pollution on Communication	Textbook EBA Q & A DI
Hearing Sound in Different Medium	• Discovers by experimenting that sounds are heard differently when the sound source changes. • By conducting experiments, students discover how sound changes depending on the medium through which it travels.	6	• Ant Galleria and Musical Instruments	Textbook EBA Q & A DI
Speed of Sound	• Compares the speed of sound in different environments.	4	• Owls and Fast Trains	Textbook EBA Q & A DI
Interaction of Sound with Matter	• Gives examples of reflection and absorption of sound. • Predicts and tests predictions to prevent the spread of sound. • Explains the importance of sound insulation. • Gives examples of acoustic applications. • Designs environments that serve as an example for sound insulation or acoustic applications.	8	• Echolocation of Bats and the Visually Impaired • Mimar Sinan and his work Süleymaniye Mosque	Textbook EBA Q & A DI

[1] EBA: Educational Technology Platform, Q&A: Question and Answer, DI: Direct Instruction.

In experimental groups, students were allowed to explore science topics within the sound and its properties unit in the context of a specific biomimetic scenario. They were then tasked with designing or creating a model inspired by nature. In two of the design activities, namely "Towards the Summit" and "Pantograph Making", students were only required to plan the design or model. However, in the other two design activities, they were expected to create a design or model.

Implementation Procedure/Treatments

The implementation of lesson plans prepared based on a biomimicry-enriched engineering design approach, along with lesson plans prepared based on textbooks as prescribed by the standard curriculum, began in March

https://doi.org/10.33225/jbse/25.24.918

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

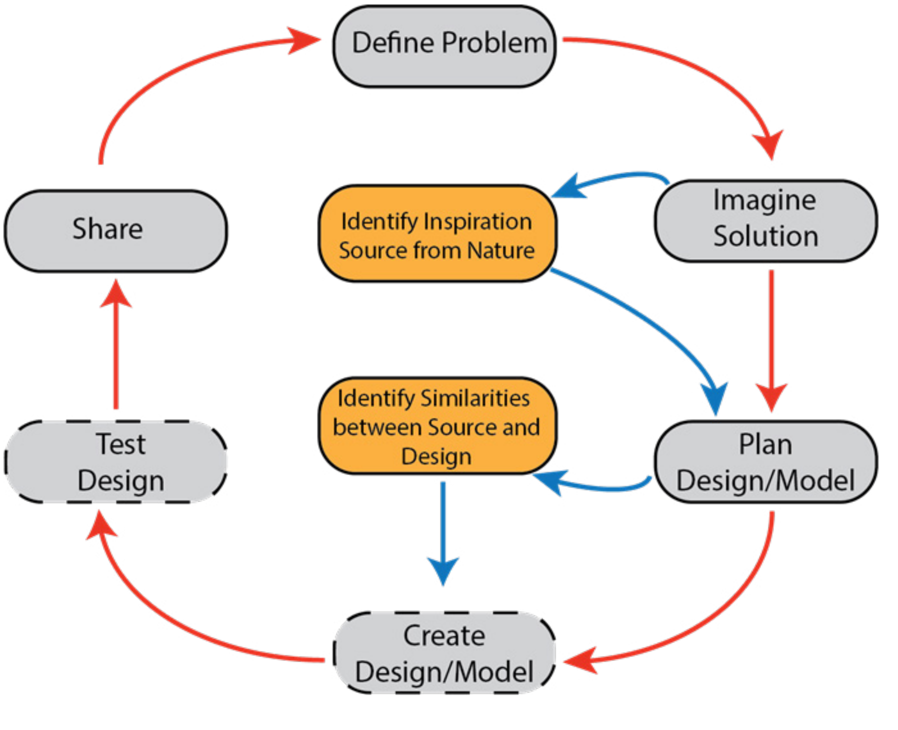
2023 and continued for four weeks, totaling 22 class hours, during the second semester of the academic year. The lesson plans prepared for the experimental and control groups were implemented by two different teachers, one of whom was the researcher. The other teacher was also an experienced teacher in design-based teaching and biomimicry. Before the implementations, the two teachers discussed the lesson plans and implementation procedures to ensure consistent instructions during the procedure.

While implementing lesson plans with a biomimicry-enriched engineering design-based approach in the experimental group, students were divided into cooperative groups of 4-5. These groups were given engineering design activity sheets based on biomimicry principles. Engineering design activities enriched with biomimetic applications were redesigned by incorporating biomimicry practices into the engineering design process cycles found in the literature, as illustrated in Figure 1. This process was implemented in experimental group activities. The aim was to place nature-inspired resources at the center of the engineering design process and to reflect the characteristics of these inspirational sources in the designs. During the lesson, experimental group students were asked to identify the problem situation presented in the activity and find a solution by taking inspiration from nature. The activities included design tasks involving steps such as "defining the problem", "imagining a solution", "identifying an inspiration source from nature", "planning", "identifying similarities between the inspiration source and design", "creating a model by applying the solution", "testing", and "sharing". The red arrows in the figure highlight the core engineering design steps, while the blue arrows indicate the biomimicry enrichment steps integrated into this process. Some of the dashed steps might have been omitted in specific design activities during implementation.

The real-life problems in the activity sheets were read aloud in class, and students were given free time to discuss them within their groups and propose solutions from nature. The classroom teacher guided students as they presented their solution proposals for these problems. Students were given time until the next class to think more about the solutions to the questions at hand, conduct research, review their designs, and gather materials. In the following class, students were given time to present their group's solution proposals and create models based on their designs.

In the control group, the students also worked in cooperative groups of 4-5, using lesson plans that were prepared in accordance with the existing science curriculum. These lesson plans were primarily delivered through presentations, hands-on experiments, questioning with direct instruction, and made use of activities found in the EBA (Educational Technology Platform) and the science textbook.

Figure 1
Biomimicry-Enriched Engineering Design Process



https://doi.org/10.33225/jbse/25.24.918

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

Data Analysis

For the quantitative analysis to answer the research question, IBM Statistical Package for the Social Sciences (SPSS) 23 was used. For descriptive analysis, we calculated the mean, median, mode, standard deviation, skewness, and kurtosis for each variable in both groups. For inferential analysis, we conducted a Multivariate Analysis of Covariance (MANCOVA) on pre-test and post-test scores. This was done to see how biomimicry enriched engineering design teaching (the independent variable) affected students' attitudes towards biomimicry, association with daily life, and attitudes towards STEM (the dependent variables), while controlling for their pre-test scores.

Ethical Considerations

This study followed the ethical guidelines of the Declaration of Helsinki. Participants gave informed consent after learning about the study's purpose, procedures, their right to withdraw, and data confidentiality. Their data was anonymized using unique, randomly generated IDs to protect privacy and minimize risks. The Institutional Review Board of Kocaeli University approved the study (Approval No: E-10017888-100-366857 and date of approval: 09.02.2023).

Research Results

Descriptive Results

In this study, descriptive statistical analyses were conducted to determine whether the pre-test and post-test scores for both the experimental and control groups followed a normal distribution. These scores were collected before and after the implementations, respectively. Table 4 presents the mean, mode, median, standard deviation, skewness, and kurtosis values of the pre-test and post-test scores obtained from BAQ, ADLT, BAS, and SAS. The skewness and kurtosis values for pre- and post-test scores on the BAQ, ADLT, BAS, and SAS scales for students in the sample were found to be between -1 and +1. Therefore, as the skewness and kurtosis values did not exceed the critical range and the mean, median, and mode were approximately equal, the scores were assumed to be normally distributed (Pallant, 2016).

Table 4
Descriptive Statistical Findings Related to Pre-Test BAQ and Pre- and Post-Tests of ADLT, BAS, and SAS

	Instrument	Group	*M*	*Mdn*	*Mo*	*SD*	Skewness	Kurtosis
PRE-TEST	BAQ	E1	5.97	6	8	1.750	0.756	1.001
		C1	5.81	6	8	2.191	-0.179	-0.509
		C2	5.65	5	9	1.999	-0.780	1.008
		E2	5.44	6	9	1.739	-0.278	-0.943
		Total	5.72	6	10	1.905	0.248	0.148
PRE-TESTS	ADLT	E	11.79	12	12	3.069	-0.048	-0.476
		C	11.37	11	8	3.608	0.228	-0.944
		Total	11.67	10	12	3.360	0.021	-0.599
	BAS	E	77.46	77	70	14.68	0.032	-0.077
		C	80.21	79.5	73	14.335	0.103	-0.674
		Total	78.78	78	73	14.50	0.054	-0.365
	SAS	E	120	120	119	22.02	-0.950	-0.24
		C	124.23	124	112	24.80	-0.334	0.136
		Total	122.14	122	112	23.37	-0.192	0.090

https://doi.org/10.33225/jbse/25.24.918

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

	Instrument	Group	*M*	*Mdn*	*Mo*	*SD*	Skewness	Kurtosis
POST- TESTS	ADLT	E	18.4	19	22	3.80	-0.514	-0.146
		C	11.94	12	12	3.90	-0.146	-0.874
		Total	15.33	16	20	5.07	-0.166	-0.782
	BAS	E	85.6	86	86	11.85	0.090	-1.001
		C	77.98	75.5	68	15.86	-0.053	-0.636
		Total	82	80	86	14.37	-0.225	-0.415
	SAS	E	133.98	136	143	20.74	-0.233	-0.383
		C	121.32	123.5	118	26.30	-0.710	0.867
		Total	127.94	130	118	24.29	-0.666	0.924

E: Experimental, C: Control, M: Sample mean, Mdn: Median, Mo: Mode, SD: Standard Deviation

Inferential Results

Preliminary Assumption Checks and Determining Covariates

For MANCOVA analysis to be conducted, a series of assumptions must be met. These assumptions were tested, and the results were evaluated for: sample size, normality, Levene's test for equality of variances, univariate and multivariate outliers, multicollinearity and singularity, homogeneity of variance-covariance matrices, and homogeneity of regression. Based on the results, as the assumptions were met, there were no issues with proceeding with the MANCOVA analysis.

In this study, the pre-test scores of ADLT, BAS, and SAS were considered as potential covariates to reduce error variance and eliminate systematic bias. According to Stevens (2009), even if groups do not differ significantly in terms of pre-test scores, pre-test scores should still be used as covariates to reduce error variance. In this study, no statistically significant difference was found between the pre-test scores of BAS ($t(107) = 0.99$, $p = .325$), SAS ($t(107) = .88$, $p = .383$), and ADLT ($t(107) = .66$, $p = .509$) for experimental and control group students. For these reasons, these three pre-test scores were selected as covariates. According to Pallant (2016) and Stevens (2009), covariates should be continuous variables, the reliability of scores obtained from the covariate should be high (>0.70), and covariates should have a significant correlation with the dependent variables, while the correlation between covariates should be less than .80. When Table 5 is examined, the biomimicry awareness questionnaire (pre-BAQ) used to equalize the groups was not selected as a covariate because both its reliability was below .70 ($\alpha = .610$) and it did not have a significant correlation with the dependent variables post-BAS, post-ADLT, and post-SAS. On the other hand, pre-BAS, pre-ADLT, and pre-SAS were determined as covariates because they had significant correlations with the dependent variables and had correlations less than .80 with each other.

Table 5
Correlations between Covariates and Dependent Variables

Variables	pre-ADLT	pre-SAS	pre-BAS	post-ADLT	post-SAS	post-BAS
pre-BAQ	.160	.151	.017	.175	.171	.056
pre-ADLT		.267**	.007	.497**	.246*	.039
pre-SAS			.562**	.156	.572**	.335**
pre-BAS				.105	.518**	.684**
post-ADLT					.475**	.382**
post-SAS						.685**
post-BAS						1

**Correlation is significant at the .01 level (2-tailed).
* Correlation is significant at the .05 level (2-tailed).

https://doi.org/10.33225/jbse/25.24.918

ISSN 1648-3898 /Print/
ISSN 2538-7138 /Online/

MANCOVA Results

In this study, a MANCOVA analysis was conducted to determine if there was a significant difference between the experimental and control groups in their post-test total scores for BAS, SAS, and ADLT. The analysis controlled the effects of pre-test scores for these same variables. Teaching methods (experimental and control group implementations) named as group served as the independent variable, while the post-test scores for BAS, SAS, and ADLT were the dependent variables. The pre-test scores for these variables were used as covariates. The results of the MANCOVA analysis are presented in Table 6.

Table 6
MANCOVA Results

Independent Variables	Wilks' Λ	*F*	*df1*	*df2*	*p*	*η²*	Observed Power
Intercept	0.845	6.25	3	102	0.001	0.155	0.845
pre-ADLT	0.648	18.44	3	102	< .001	0.352	0.648
pre-SAS	0.762	10.64	3	102	< .001	0.238	0.762
pre-BAS	0.520	31.33	3	102	< .001	0.480	0.520
Group (experimental-control)	0.460	39.88	3	102	< .001	0.540	0.460

According to MANCOVA analysis, results indicated a statistically significant difference between the experimental and control groups in terms of post-test scores for BAS, SAS, and ADLT, after controlling for the pre-test scores ($F(3, 102) = 39.88$; $p < .001$; Wilks' $\Lambda = 0.460$; partial eta squared = 0.540). To determine which specific dependent variables contributed to this significant difference, a post hoc analysis was conducted. Using a Bonferroni correction, a significance level of .017 was determined. The results showed that the post-test scores for ADLT ($F(1, 104) = 113.43$, $p < .001$, partial eta squared = 0.522), BAS ($F(1,104) = 27.04$, $p < .001$, partial eta squared=0.206), and SAS ($F(1,104) = 20.68$, $p < .001$, partial eta squared = 0.166) were all significantly different between the experimental and control groups at the .017 level. These results indicate that, after controlling pre-test scores, there was a significant difference between the experimental and control groups in terms of post-test scores for biomimicry attitudes, daily life associations, and STEM attitudes. To determine the magnitude of these differences, effect sizes (eta squared, η^2) were calculated. Eta squared indicates the proportion of variance in the dependent variable that is accounted for by the independent variable. The results showed large effect sizes for all three dependent variables (ADLT $\eta^2 = 0.522$; SAS $\eta^2 = 0.166$; BAS $\eta^2 = 0.206$), with the largest effect size for ADLT post-test scores (Table 7).

Table 7
Comparison Results of Groups for Dependent Variables

	Dependent Variables	*df*	*MS*	*F*	*p*	*η²*
Group	post-ADLT	1	1073.102	113.43	p < .001	0.522
	post-SAS	1	6305.656	20.68	p < .001	0.166
	post-BAS	1	2417.463	27.04	p < .001	0.206

When examining the comparison results obtained by looking at the values from the MANCOVA, it was observed that there was a significant difference in favor of the experimental group in terms of post-test scores for ADLT, BAS, and SAS ($p < .05$). According to the results, it is observed that the mean post-test score for ADLT in the experimental group ($M = 18.353$, $SD = 0.409$) is higher than the mean score of the control group ($M = 12.017$, $SD = 0.428$), indicating a difference in favor of the experimental group. Similarly, the mean post-test score for SAS in the experimental group ($M = 135.272$, $SD = 2.322$) is higher than the mean score of the control group ($M = 119.914$, $SD = 2.432$), indicating a difference in favor of the experimental group. Likewise, when looking at the mean post-test scores for BAS, the mean of the experimental group ($M = 86.537$, $SD = 1.258$) is greater than the mean of the control group ($M = 77.027$, $SD = 1.317$), indicating a difference in favor of the experimental group. To sum up, the experimental

https://doi.org/10.33225/jbse/25.24.918

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

groups performed better than the control groups on all three measures (ADLT, SAS, and BAS). The average scores for the experimental groups were higher than the average scores for the control groups in each case.

Discussion

During the implementation of this study, the biomimicry-enriched engineering design activities conducted in the experimental group fostered an active learning environment. Students collaborated in small groups, with teacher guidance, to solve and explore real-world problems, drawing inspiration from nature for solutions. This active, real-life-connected learning approach, inherent in the biomimicry-enriched engineering design teaching, likely improved the experimental group's ability to relate sound concepts to their everyday experiences compared to the control group. One key finding of the study was that the largest effect was observed in students' ability to associate scientific concepts with daily life (Table 7). This suggests that biomimicry, as a teaching approach, is particularly effective in helping students see the relevance of science beyond the classroom. This result is consistent with Gardner's (2012) assertion that biomimicry encourages students to think creatively about real-world problems by observing and learning from nature. Furthermore, the engineering design activities allowed students to work collaboratively, fostering a deeper understanding of the material and enhancing their problem-solving abilities, as suggested by Hynes et al. (2011). Students generally find sound a challenging science concept (Caleon & Subramaniam, 2010; Eshach & Schwartz, 2006; Küçüközer, 2009; Wittmann et al., 2003) and have trouble relating it to their everyday experiences (Aksoy et al., 2023). In fact, knowledge that cannot be related to daily life cannot go beyond mere memorization (Demircioğlu et al., 2012). When the instructional material is relevant to their lives, however, students find the content more useful and learn it more meaningfully. The current study found that biomimicry-enriched engineering design-based teaching was an effective way to help students understand the relevance of science to their daily lives (Pauls, 2017). This approach made the subject more engaging and meaningful, leading to a stronger association with daily life in the sound and its properties unit, as well as increased attitudes toward biomimicry and STEM compared to control group teaching.

By focusing on biomimetic examples, such as the use of echolocation by dolphins or sound insulation inspired by owl feathers, students in the experimental group were able to see how the principles of sound propagation, reflection, and insulation are used both in nature and in human-made technologies. This association with daily life is critical because it enhances students' engagement, motivation, and retention of knowledge (Ersanlı, 2016; Jacobs et al., 2022; Kandemir et al., 2022; Kara, 2016; Savran Gencer et al., 2020; Sumrall et al., 2018) and their success in science. By involving students in such activities, the instructional approach fostered situated learning, where students' understanding of abstract scientific concepts is grounded in practical, real-life problems (Lave & Wenger, 1991; Rehmat et al., 2024). This is particularly important for topics like sound, where students often struggle to visualize how sound waves behave in different environments. The hands-on nature of the biomimicry-enriched tasks, such as designing soundproofing solutions or examining the different mediums through which sound can travel, helped students conceptualize how these principles apply in everyday scenarios, such as controlling noise pollution or improving communication systems (Gardner, 2012). Furthermore, the biomimicry approach likely promoted deeper cognitive processing, as students were not only required to understand the concept of sound but also to analyze, synthesize, and evaluate how nature solves sound-related challenges. For instance, students' designs that mimicked owls' silent flight for sound insulation or dolphins' echolocation for communication systems demonstrated their ability to transfer their understanding of sound from biological examples to human-designed technologies. This ability to transfer knowledge across domains is a key indicator of meaningful learning and the development of critical thinking skills (Faber et al., 2013; Fortus et al., 2005).

The findings of this study revealed that biomimicry-enriched engineering design-based teaching significantly improved students' attitudes toward STEM. This positive shift in STEM attitudes aligns with previous research emphasizing the role of innovative teaching strategies, such as engineering design-based learning, in promoting student interest and engagement in STEM disciplines (NAENRC, 2014; Ring et al., 2017). Biomimicry is very suitable for gaining engineering design skills as a solution-oriented approach with thinking skills. From this, it can be inferred that one of the effective methods that will contribute to students' invention and creativity development with inspiration from nature is the STEM approach (Gardner, 2012; Sumrall et al., 2018). For this reason, biomimicry research, which includes STEM or engineering design-based education in schools, contributes to the development of individuals' abilities in various fields by comparing them with experiential learning environments and real-life problems (Avcı, 2019). In particular, the integration of biomimicry in the instructional process appears to provide students with a hands-on, interdisciplinary approach to learning that fosters positive attitudes toward STEM fields. This is consistent

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

with findings from studies such as Gencer et al. (Savran Gencer et al., 2020), which highlight that students exposed to design-based learning are more likely to develop favorable attitudes toward science and engineering.

The results of the study suggest that biomimicry, as a pedagogical tool, not only enhances students' cognitive understanding of STEM topics in relation to real life contexts but also positively influences their affective dispositions toward learning science. The improvement in biomimicry attitudes is consistent with prior research, such as that of Gardner (2012), who argues that nature-inspired learning encourages curiosity and engagement by showing students the relevance of science in solving real-world problems. By integrating biomimicry into the engineering design process, students are exposed to the practical applications of scientific knowledge, fostering a sense of wonder and appreciation for how nature can inspire technological solutions (Pauls, 2017), which in turn develops a positive attitude towards biomimicry. Moreover, the strong positive shift in biomimicry attitudes in this study can be attributed to the hands-on, nature-inspired design tasks that students engaged in during the lessons. For example, activities such as creating sound-insulating designs inspired by owl feathers or using ant galleries in whistling acacia as a model for building musical instruments provided students with tangible, relatable examples of how biomimicry works. These activities helped students connect abstract scientific concepts to concrete, real-world applications, which is crucial for developing positive attitudes toward learning (Canbazoğlu Bilici et al., 2021; Kaltakci & Eryilmaz, 2011). As suggested by research in affective education, students who find personal relevance and emotional engagement in their learning tasks are more likely to develop positive attitudes toward the subject matter (Faber et al., 2013).

Although the study's results are promising, it is important to recognize its limitations. One potential challenge is the need for adequate teacher training and resources to implement biomimicry-enriched engineering design lessons effectively. Not all teachers may feel comfortable integrating biomimicry into their lessons without appropriate professional development and support (NAENRC, 2014). As such, future research could explore the most effective ways to train teachers in this approach and provide them with the necessary tools and resources. Additionally, while this study focused on sixth-grade students, future research could investigate how biomimicry-enriched teaching influences STEM attitudes, association with daily life, and biomimicry attitude across different grade levels. The study focused on a specific set of sound-related concepts, and the effectiveness of the teaching design may vary across other scientific topics. Future research should explore whether similar improvements in the association with daily life can be achieved in other science units, such as electricity or motion. Additionally, further research is needed to explore how these factors develop over time. Longitudinal studies could investigate whether the positive effects observed in this study persist as students advance through higher levels of education and whether they continue to apply biomimicry concepts in other areas of science and technology. It would also be valuable to examine the effects of biomimicry-enriched teaching on students from diverse educational backgrounds to determine whether these findings are generalizable across different populations. Finally, future studies could incorporate more detailed qualitative methods, such as interviews or classroom observations, to gain a deeper understanding of how students make connections between science concepts and daily life during biomimicry-enriched teaching.

Conclusions and Implications

This study examined the effects of biomimicry-enriched engineering design-based activities on 6th-grade students in the "Sound and its Properties" unit. The findings of the study indicate that biomimicry-enriched engineering design-based teaching significantly enhances students' association with daily life, attitudes toward biomimicry, and STEM. Globally, there's a demand for innovative methods to make science education more relevant to real-life situations. One promising approach is biomimicry, which allows students to observe science in action and connect theoretical concepts with practical applications in nature. By exposing students to nature-inspired solutions and allowing them to engage in hands-on design activities, this instructional approach not only fosters creativity and innovation but also instills a deeper appreciation for the relevance of science in everyday life. These results suggest that biomimicry in engineering design-based applications can play a vital role in improving STEM education by making scientific concepts more engaging, relatable, and applicable to real-world challenges. This study not only addresses specific educational needs but also contributes to the international discourse on effective STEM education. The principles and outcomes observed in this biomimicry-enriched approach have broad applicability across diverse global contexts, offering insights for enhancing student engagement and attitudes in science education worldwide.

https://doi.org/10.33225/jbse/25.24.918

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

This study has several educational implications derived from the results regarding students' association with sound concepts in daily life, their STEM attitudes, and their biomimicry attitudes. To begin with, the improvement in students' association with sound concepts in daily life highlights the importance of integrating real-world contexts into science education. Teachers should incorporate biomimetic examples, such as animal echolocation or noise control inspired by nature, to make abstract concepts more accessible and engaging. By connecting the properties of sound, such as reflection and insulation, to familiar contexts—whether natural or technological—students can develop a more nuanced understanding of the subject matter, which in turn can lead to greater engagement and improved learning outcomes. Moreover, this approach encourages students to think about science in a more integrated, interdisciplinary way. The association of sound concepts with daily life is not limited to physics; it also involves engineering (soundproofing designs), biology (echolocation in animals), and even environmental science (noise pollution). This interdisciplinary thinking is a key goal of STEM education, which seeks to prepare students to solve complex, real-world problems that do not fall neatly into one subject area. Secondly, the positive shift in STEM attitudes suggests that interdisciplinary approaches can significantly enhance student engagement. Combining biology, physics, and engineering in biomimetic tasks prepares students for complex problem-solving, a key skill for future STEM careers. Moreover, the interdisciplinary and creative aspects of the biomimicry-enriched design tasks likely contributed to the enhanced STEM attitudes observed in this study. Unlike conventional classroom activities, design-based tasks allowed students to take ownership of their learning by developing solutions to real-world problems, promoting a sense of agency and accomplishment. Thirdly, the enhancement of biomimicry attitudes underscores the potential of nature-inspired design to foster creativity. By drawing on natural examples, teachers can provide students with a more relatable and engaging way to understand complex scientific concepts, potentially making STEM subjects more accessible and appealing to a broader range of students. Additionally, the improvement in biomimicry attitudes could have long-term implications for students' career interests and aspirations in STEM fields. Positive attitudes toward biomimicry may inspire students to pursue further studies or careers in fields such as environmental engineering, biology, and sustainable technology, where biomimicry plays a crucial role. As the global emphasis on sustainability and innovation grows, developing a generation of students who are not only proficient in STEM but also passionate about nature-inspired solutions could be vital for future technological advancements. Finally, the success of this intervention suggests a need for curricula that emphasize hands-on, design-based learning. Policymakers and educators should consider integrating biomimicry into STEM education to better prepare students for sustainable innovation.

Declaration of Interest

The authors declare no competing interest.

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Received: *May 26, 2025* Revised: *July 27, 2025* Accepted: *September 05, 2025*

Cite as: Kaltakci-Gurel, D., & Gokce, E. (2025). Effects of biomimicry-enriched engineering design-based teaching on students' association with daily life, STEM attitude, and biomimicry attitude in sound and its properties unit. *Journal of Baltic Science Education*, *24*(5), 918–934. https://doi.org/10.33225/jbse/25.24.918

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https://doi.org/10.33225/jbse/25.24.918